THE STELLAR WIND IN THE BO V-TYPE ECLIPSING BINARY Y CYGNI

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ABSTRACT

The double-lined eclipsing binary system Y Cygni (HD 198846) has well-determined orbital elements, absolute dimensions, and rate of apsidal motion. In several high-dispersion SWP images taken near (but not in) eclipse and in one at quadrature, we studied the profiles of the resonance lines of Si IV, C IV, and N V. C IV is very broad, and the absorption minima are shortward shifted by 160 km s^{-1} with respect to Si IV. N V is weak but is shortward shifted by a similar amount and has a broad shortward wing. In general, the spectrum is similar to that of the single BO V-type star τ Scorpii. In the spectrum obtained at quadrature, the C IV profile is shifted in accordance with the orbital motion of the hotter, less massive star. Therefore, it is likely that the wind-borne C IV absorption originates in this star.

By fitting the C IV and N V lines with synthetic profiles computed from the program written by Olson (1982 and references therein), we obtained a terminal velocity of 1500 km s^{-1}. Application of the technique of Garmany et al. (1981) yields $\dot{M} = 10^{-8.4} M_{\odot}$ yr^{-1}.

INTRODUCTION

Y Cygni is a double-lined eclipsing binary that is noteworthy in being one of the best-determined cases of apsidal motion. It consists of a pair of BO V-type stars. Giuricin et al. (1980) give the most recent tabulation of the absolute dimensions of the components. They find that the radii of the hotter and the cooler star are 0.182 and 0.237, respectively, times the mean separation. Therefore, the system is well detached, and we expect the components to be structurally similar to single stars. The rotation velocity of each, 145 km s^{-1} (Levato 1975), is significantly greater than the synchronous rotational velocity, 100 km s^{-1}. On the basis of an early IUE observation, Heap (1981) informed us that the system has a stellar wind.

OBSERVATIONS AND RESULTS

We obtained a high-dispersion image (SWP 19650) of the system with IUE just before primary eclipse, when the spectrum was single-lined. The two stars contribute roughly equally to the combined light: from the equatorial temperatures and the luminosity ratio given by Giuricin et al. (1980) and from fluxes given by Kurucz (1979), we estimate that the hotter star is about 20% brighter at 1500 Å.

The principal evidence for a wind is that the short-wavelength wing of the C IV resonance doublet ($\lambda\lambda$1548,1550) is broad, and that its absorption minima are shifted by about 160 km s^{-1} toward shorter wavelengths relative to the photosphere. The N V doublet ($\lambda\lambda$1238,1242) is also present, although weakly, at a similar radial velocity. The motion of the photosphere is represented by the radial velocities of the Si IV resonance lines, which are symmetrical and usually originate in the photosphere in stars of this spectral type.

Heap's original image, SWP 6388, was obtained at quadrature, when the hotter star was approaching with a heliocentric radial velocity of -310 km s^{-1}. In this image, the absorption minima of C IV appear at a radial velocity of -470 km s^{-1}, again shortward shifted by 160 km s^{-1}. N V shows the same behavior. Thus, the orbital motion of the stellar wind follows that of the hotter star, and we conclude that the wind is associated with this star.

We have compared the spectrum that we obtained at conjunction with archival IUE spectra of single BO-type stars. The C IV profile in Y Cyg is similar to that in τ Scorpii (BO V), except that the Doppler shift of the minima in the latter star is only -100 km s^{-1} relative to the photosphere. Since the Si IV lines have a noticeably broad shortward wing in τ Sco but not in Y Cyg, however, the two stars are certainly not identical. On the other hand, the BO.3 IV-type star δ Scorpii shows only minimal wind broadening of the C IV doublet, and its N V lines are narrow. That such differences exist among single stars of the same spectral type makes it understandable that the components of Y Cyg have winds of different strengths.

A plausible hypothesis might be that the wind of the hotter component of Y Cyg is spectroscopically similar to that of τ Sco, while the cooler component has a wind like that of δ Sco. Then, the composite, single-lined spectrum shows the C IV line cores at their true depths, because they are approximately equal in depth in the two stars, while the C IV wing and the N V lines are weaker in the composite spectrum than they are in the hotter star alone, because their light is diluted with light from the companion, which has a weak wind. In order to test this hypothesis, it would be necessary to obtain an exposure at mid-eclipse.

ANALYSIS AND CONCLUSIONS

We computed synthetic C IV and N V profiles at the Colorado Regional Data Analysis Facility with the program COMPAR (Olson 1982 and references therein), and we fitted them to the observed profiles in both Y Cyg and τ Sco. Table 1 lists the parameters that gave a good fit to each star; T is the line-center radial optical depth for the shortward component of the doublet (Olson 1982) and v_∞ is the terminal velocity of the wind.

TABLE 1

Profile Fitting Parameters from COMPAR

Star (Image)	v_∞ (km s^{-1})	T(C IV)	T(N V)
Y Cyg (SWP 19650)	1500	0.65	0.15
τ Sco (SWP 13713)	1500	0.60	0.20

With these values, we used the procedure given by Garmany et al. (1981) to estimate the mass-loss rate, $\dot{M}$. The fact that the procedure was designed for hotter (O-type) stars means that the assumed ionization balance may not be correct in our case. The procedure assumes that nearly all the carbon in the wind is quadruply ionized and that the only important ions of C and N are the third and the fourth. To check the reliability of our results, Table 2 compares values of $\dot{M}$ derived by this technique with values derived by more sophisticated analyses of τ Sco and μ Columbae.

TABLE 2

Comparison with Independently Derived Mass-Loss Rates

Star	Type	Author	log $\dot{M}$ ($M_\odot$ yr^{-1}) (other study)	log $\dot{M}$ ($M_\odot$ yr^{-1}) (this technique)
Y Cyg	(BO V)x2	---	---	-8.4
τ Sco	BO V	Hamann (1981)	-8.9 $\pm$ 0.5	-8.3
μ Col	O9 V	Olson and Castor (1981)	-8.2	-8.1

The agreement is reasonably good. We conclude that, even for effective temperatures near 30000 K, the technique of Garmany et al. (1981) gives a

reasonable estimate of $\dot{M}$.

Since our spectrum of the hotter component of Y Cyg is diluted with light from the companion, which has a weaker wind, the mass-loss rate given in Table 2 is a lower limit to the mass-loss rate of the hotter component. Its accuracy could be improved if a spectrum at mid-secondary eclipse could be obtained. Then, only about 20% of the combined light would come from the cooler star.

Since the mass and radius of the hotter component are well determined from the orbit, this star could be important in the study of the dependence of terminal velocity and mass-loss rate on the stellar parameters, provided that the properties of the wind are not strongly influenced by the companion. That the wind does behave approximately as the wind of a single star is suggested, firstly, by the fact that, in a series of exposures taken as the system approached primary eclipse, the C IV profile does not vary noticeably with orbital phase. Secondly, if the wind is like that of τ Sco, then, according to Hamann's (1981) model, it reaches terminal velocity 2.5 stellar radii from the center of the star. In Y Cyg, this distance equals 0.46 times the average separation of the stars, a. Since the companion's photosphere lies at a distance of 0.76 a, the wind reaches it only after attaining terminal velocity. Thus, provided that the wind of the cooler star is truly very weak, so that wind-wind interactions are unimportant, the hotter star's wind probably acts like that of a single star.

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